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research division

To: Dr. D. Mills
Director of Research

COLD FUSION AT DARLINGTON NGS?
or
VERIFYING TRITIUM INVENTORIES

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Anomalous quantities of heat were reported from an immobilized tritium container (ITC) at Darlington NGS. Since the ITC contained tritium and deuterium absorbed on titanium, cold fusion was suggested as a possible source of excess heat. A calorimeter was constructed to measure the heat output of the ITC. In addition, neutron emission was measured with a helium-3 detector. At the time of our measurements, no excess heat above heat from beta decay was detected and no neutrons (above background levels) were observed. Note that calorimetry was able to determine the tritium content of the ITC to within 2%. Calorimetry can determine the tritium contents of an ITC or other tritium container without removing any tritium from the container. No corrections for beta decay are required and the tritium inventory accuracy is independent of the number of samples of tritium that have been added or withdrawn. Calorimetry could be a useful way of verifying the tritium inventory in the vault or in smaller tritium containing vessels.

1. Introduction

The surface temperature of the Darlington immobilized tritium container, following initial loading with about 450,000 Ci of tritium, was reported to be hotter than expected. Tony Busigin of Nuclear Engineering Department calculated that beta decay should produce a surface temperature only about 6 degrees above ambient but temperatures more than twice that above ambient were reported. Because of the very approximate nature of the surface temperature calculation, Research Division was asked to measure the heat output of the ITC. Excess heat above that calculated for beta decay would result in additional tests looking for cold fusion.

job	file	date	report no.
16-563	819.143	January 4, 1990	89-305-K

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2. Calorimetry

The heat output of the ITC can be measured by placing the ITC in an insulated box, flowing a constant amount of air through the box, and making a note of the temperature of the air flowing into and out of the box. The heat loss through the insulated walls of the box can be corrected for by calibrating the box using an empty ITC with resistance heating to simulate beta decay. With this calibration procedure it is not necessary to accurately know the air flow rate. You must, however, be able to reproduce the flow from one measurement to the next. In these experiments, a low cost rotameter was used at its full scale output to give the results described below.

3. Insulated Box Construction

The box was designed to fit the Darlington ITCs. It was constructed out of 5-cm thick STYROFOAM SM and white glue. The joints were all sealed with RTV (silicon) in order to eliminate leaks. Holes were placed in diagonally opposite corners. The direction of air flow was from the hot end of the ITC, which contained the tritium, toward the cooler end.

4. Calibration Details

The prototype ITC, (See Figure 1) was wrapped with insulated heating tape at one end to simulate the heat given off by beta decay. The tape was connected to an analog wattmeter which was in turn connected in series to a variac. This configuration allowed us to accurately know how much power was being supplied to the heating tape. Once the ITC was carefully placed in the box, the box was closed and then sealed with RTV. The wires of the heating tape were fed into the box through the one inch air inlet hole. The outlet hole is actually a feed-through for a quarter inch ID plastic tube that connects the box to the rotameter. A rotameter was used to get a reproducible flow rate of air which was sucked through the box with a small bellows pump. We chose to suck the air instead of blowing it through, because blowing caused the lid to be raised causing leaks and making air flow measurements meaningless. Calibrated thermocouples were placed in reproducible locations along the ITC and at the air inlet and outlet. The readings of the four thermocouples inside the box gave a rough idea of how far from equilibrium the system was. At equilibrium, the outlet temperature stops rising. (If the box was perfectly insulated, all of the thermocouples would have read the same temperature at equilibrium. However, because some heat (3.6 watts - see Appendix A-6.0) is lost through the box walls, there is a small temperature gradient (<2 C) along the length of the box).

After choosing a wattage with the wattmeter, the air flow was started. The system was allowed to equilibrate during the night and by midday of the next day, the last twenty 15-minute readings were recorded from the thermocouple read-out and analyzed. This procedure was repeated for six wattages between 12 and 18 watts and a calibration graph of power versus the outlet and inlet temperature difference was plotted (Figure 2). A straight line fit to these data points gives the output watts.

$$W = 0.685 * dT - 1.44$$

where dt is the temperature rise between the inlet and outlet (Appendix A-4.0).

SCHEMATIC OF CALIBRATION

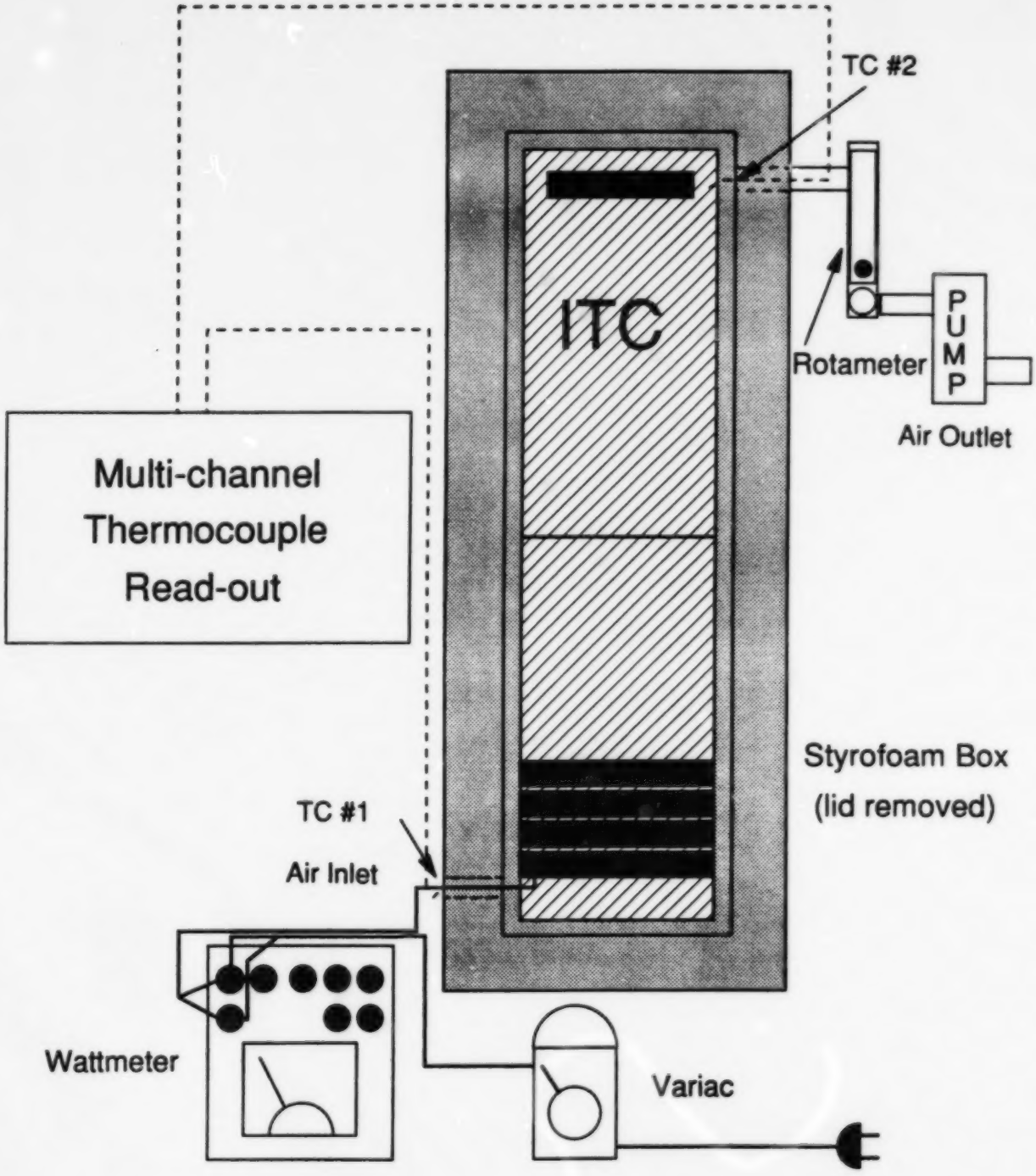

Figure 1

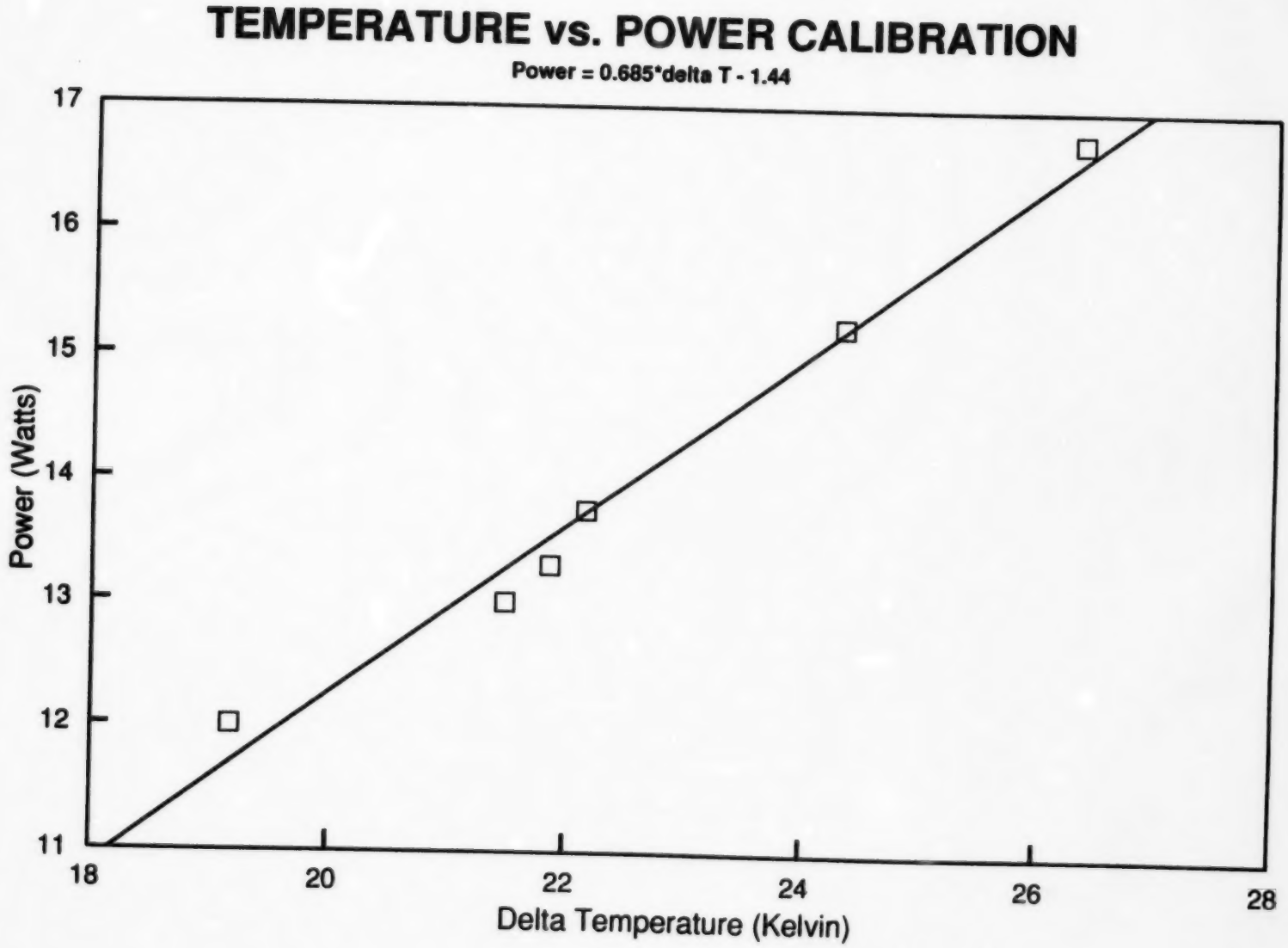
TEMPERATURE vs. POWER CALIBRATION
Power = 0.685*delta T - 1.44
Power (Watts)
17
16
15
14
13
12
11
18
20
22
24
26
28
Delta Temperature (Kelvin)

Figure 2

SCHEMATIC OF EXPERIMENT

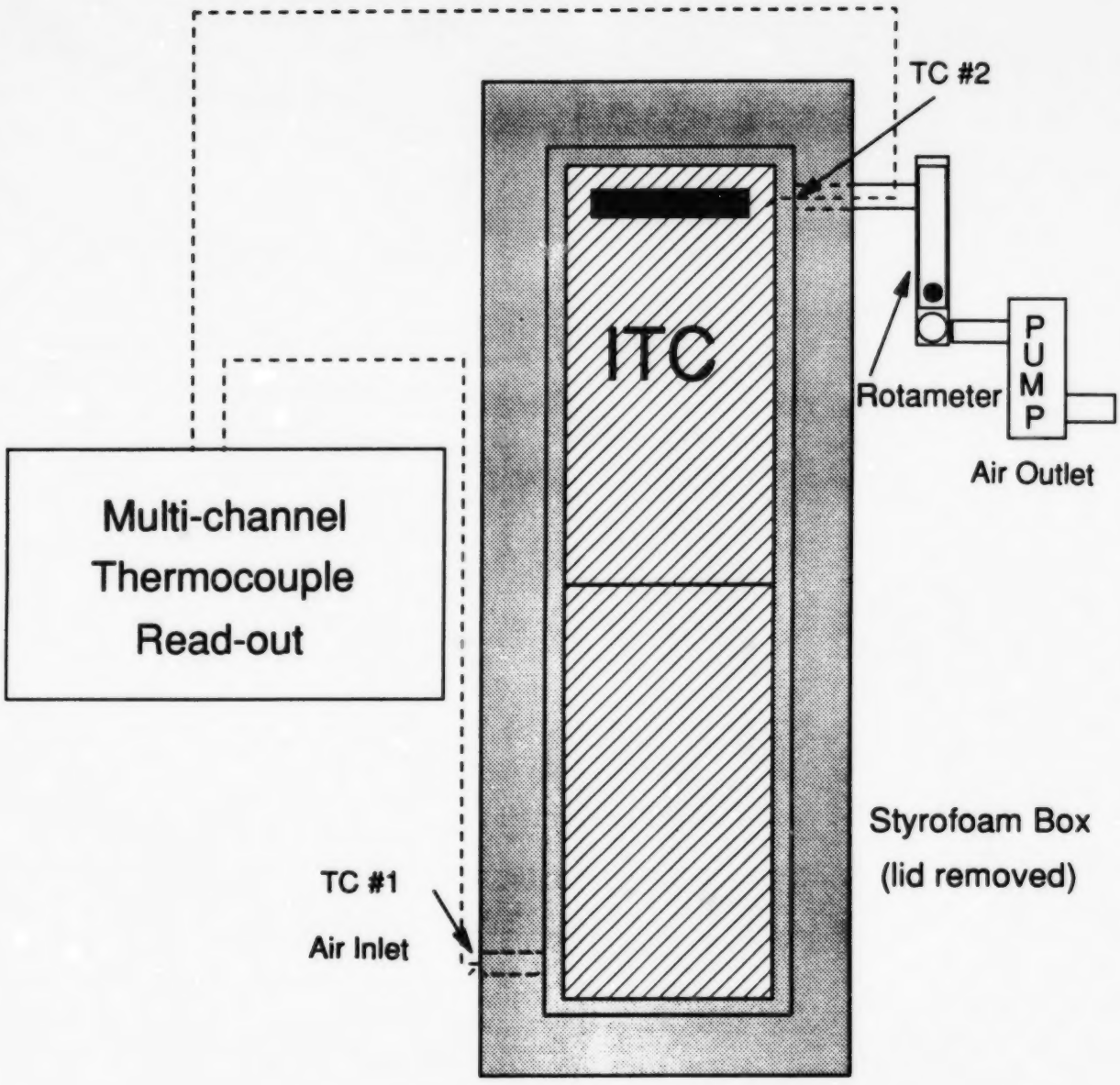

Figure 3

SIDE-VIEW OF NEUTRON COUNTING CONFIGURATION

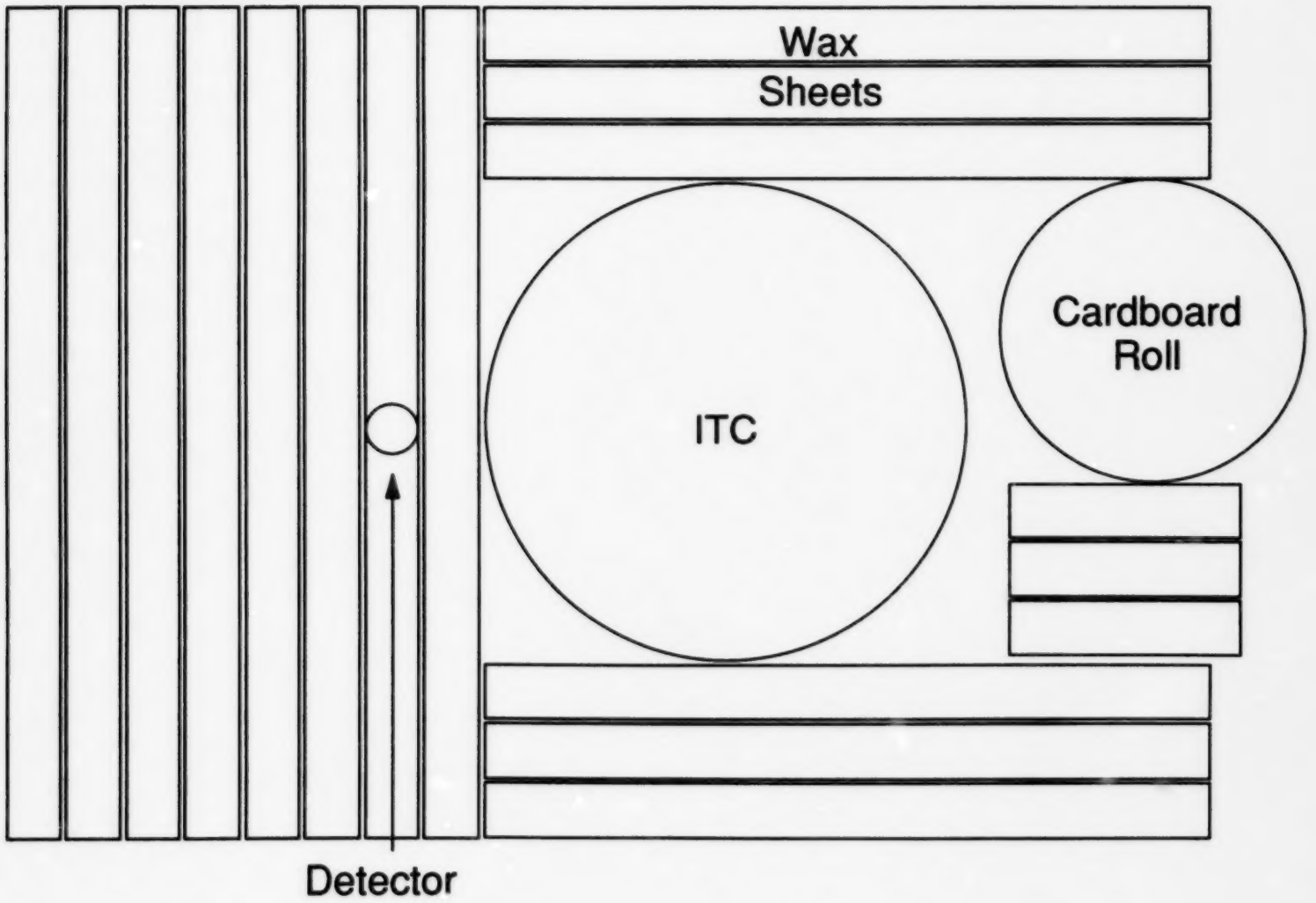

Figure 4

5. Darlington Calorimetry Measurements

On August 23, 1989, a fully charged ITC was tested at the Tritium Removal Facility (TRF) in the Darlington Nuclear Generating Station (NGS). The experimental setup, (See Figure 3), was the same as the calibration setup except there was no need for the wattmeter, heating tape, and variac. The lid was placed on the box and sealed and the system was left overnight. The next day, the last twenty thermocouple read-outs were recorded and the setup was disassembled.

6. Darlington Neutron Measurements

The experimental set-up for neutron counting can be seen in Figure 4. We used a helium-3 detector with an Ortec preamplifier, amplifier, single channel analyzer, scaler, and ratemeter. The wax surrounding the detector and the ITC acts as a moderator of fast neutrons, changing them into thermal neutrons which are more easily detected. Two containers were counted, one with 440 000 Ci of tritium and an empty container. Both were counted for 2000 seconds using identical configurations. The neutron detection geometry was calibrated with a americium-beryllium neutron source. About 2.5% of all of the neutrons leaving the source were detected, even though the detector (a one inch diameter tube) only covered about 5% of the solid angle surrounding the neutron source. The high efficiency is due in part to the wax which surrounds the neutron source and the detector. As the neutrons are thermalized in the wax moderator, some of them which would not normally pass into the helium-3 detection tube are scattered into the tube.

No neutrons over and above the background in the ITC storage vault were detected from either the empty container or the one containing tritium.

7. Experiment Results and Conclusions

Calorimetry:

1) The observed temperature rise due to the tritium in the ITC was 23.37 C (Appendix A-5.0). According to the calibration graph (Figure 2) or the power equation (Appendix A-4.0), the tritium charged ITC produced 14.56 watts $\pm$ 0.13 watts.

2) At the time of measurement, the amount of tritium remaining in the ITC (after correction for tritium decay) was 443,978 Ci (Appendix A-7.0). The amount of heat production due to beta decay of this amount of tritium is 14.80 watts. This differs from the above measurement by only 0.24 watts or 1.6%.

3) Since the amount of heat measured is not greater than can be accounted for by beta decay, no anomalous heat producing mechanisms, such as cold fusion, were occurring in the ITC at the time we made our measurements (about 9 months after the ITC was charged with tritium).

4) Since the inventory measured by the non-invasive technique of calorimetry predicted the tritium inventory of the ITC based on the sum of all of the loaded batches minus the tritium lost due to beta decay to within 1.6 %, we suggest that calorimetry be considered as a method of verifying the tritium inventory in the ITC containers as well as the tritium inventory in future shipping flasks. New Business Ventures may wish to market a calorimetry system to its tritium clients to keep track of their current tritium inventory.

Neutron Counting:

1) After a 1000 second counting period the tritium containing ITC registered 47 counts while the empty ITC registered 54 counts. After a 2000 second count, the tritium containing ITC registered 89 counts while the empty container gave 101 (Appendix A-8.0).

2) Since the counts from the tritium ITC were not greater than the control (empty) container (in fact, they were about one standard deviation lower), it can be concluded that no significant neutron producing mechanisms (including cold fusion) were occurring inside the tritium charged ITC at the time when the measurements were made (about 9 months after the initial charging with tritium).

8. Summary and Recommendations

Neutron measurements and heat measurements verified that at a time nine months after the initial tritium fillings of an ITC, no cold fusion was taking place. However, if the surface temperature of a new freshly charged ITC is found to be higher than the surface temperature of the one we have measured, we recommend that the above measurements be repeated as soon after charging as possible. While we can rule out the presence of cold fusion and excess neutrons in the tritium vault several months after charging the titanium with tritium, we can not rule out excess heat or neutron producing events shortly after charging the ITC.

We recommend that calorimetry be considered as a method of verifying the inventory of any tritium containing vessels filled at the Darlington Tritium Removal Facility.

Acknowledgments

We would like to thank Mr. John Harrison and the staff at Darlington NGS for assisting us in these measurements; and Mr. A. Busigin of Design & Development - Gen, for pointing out this potential problem and for doing the initial temperature calculations.

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APPENDIX A

EXPERIMENTAL DETAILS

1.0 Insulated Box Dimensions

Outside dimensions:	81 cm x 34 cm x 29 cm
Inside dimensions:	71 cm x 19 cm x 19 cm (lid on)
Wall thickness:	5 cm
Inlet hole diameter:	2.5 cm
Outlet hole diameter:	1 cm

2.O ITC Dimensions

Length:	69 cm
Outside diameter:	17 cm
Weight:	31 kg of ASTM 316 stainless steel, and 825 g of titanium sponge

3.0 Experimental Materials

Bellows Pump:	Metal bellows model# MB-158
Rotameter:	Porter Instrument model# B-250-8 with a 1/8" black glass ball
Tubing:	3/8" ID polyethylene
Thermocouple wire:	Copper constantan
Neutron Detector:	Helium-3 charged to 1300V

4.0 Data from Calibration of Styrofoam Box

X dT	Y Watts	Regression Output:	
19.17	12.00		
21.48	13.00	Constant	-1.435
21.86	13.30		
22.16	13.75	X Coefficient(s)	0.685
24.33	15.25		
26.35	16.75		

Watts released inside styrofoam box = 0.685*dT -1.44

(dT is the temperature rise between the inlet and outlet of the insulated box.)

5.0 Experimental Data From ITC Calorimetry

Input T (C)	Output T (C)	Input T Correlation (C)	Output T Correlation (C)	delta T (C)
22	45.7	22.56	45.85	23.29
22	45.9	22.56	46.05	23.49
22	45.7	22.56	45.85	23.29
22	45.7	22.56	45.85	23.29
22	45.7	22.56	45.85	23.29
21.8	45.7	22.36	45.85	23.49
21.8	45.7	22.36	45.85	23.49
21.8	45.4	22.36	45.56	23.19
21.8	45.7	22.36	45.85	23.49
21.8	45.4	22.36	45.56	23.19
21.8	45.9	22.36	46.05	23.69
21.8	45.7	22.36	45.85	23.49
21.8	45.4	22.36	45.56	23.19
21.8	45.2	22.36	45.36	23.00
21.8	45.4	22.36	45.56	23.19
21.8	45.4	22.36	45.56	23.19
21.8	45.4	22.36	45.56	23.19
21.5	45.4	22.06	45.56	23.49
21.5	45.7	22.06	45.85	23.78
21.8	45.7	22.36	45.85	23.49
Mean				
21.82	45.59	22.38	45.75	<u>23.36</u>
Standard Deviation				
0.13	0.18	0.13	0.18	0.19

Watts measured: 14.56 ± 0.13

6.0 Air Flow Rate and Heat Losses Through Walls of the Insulated Box

150 mm on rotameter corresponding to 22.4 standard liters per minute or 0.45 grams of air per second.

Heat Withdrawn by Air

$Q = mcdT$ where m is the mass flow rate
c is the heat capacity of air
dT is the temperature difference between the inlet and outlet

= 0.448 g/s x 1.047 J/g C x 23.36 C
= 10.96 Watts

The remaining 3.6 Watts were conducted out through the walls of the calorimeter.

7.0 Calculation of Tritium Inventory in ITC from Filling Inventory and and Heat Calculations

Batch	% Tritium	Curies	Date Oct	Years Ago	Remaining Curies	Curies Decayed
3	75.85	35234.7	19	0.85	33589.1	1645.5
4	90.08	41857.6	19	0.85	39902.7	1954.8
5	86.78	39870.0	23	0.84	38031.4	1838.6
6	93.16	42693.7	23	0.84	40724.9	1968.8
7	94.69	43205.8	24	0.84	41219.7	1986.0
8	97.04	44432.9	24	0.84	42390.4	2042.4
9	93.59	42996.7	25	0.83	41026.6	1970.1
10	97.29	44851.8	25	0.83	42796.7	2055.1
11	96.66	44731.3	26	0.83	42688.3	2043.0
12	96.24	44508.3	26	0.83	42475.5	2032.8
13	88.66	40999.0	27	0.83	39132.5	1866.5
Total	91.82	46538	1.8		443977.8	21404.0

Constants for Decay Heat Calculations

1 Curie (Ci)	= 3.7×10^{10} disintegrations per second
Avogadro's Number	= 6.023×10^{23} molecules per mole
Tritium half life	= 12.26 years
1 g of Tritium	= 9719.681 Ci
Tritium molecular weight	= 6.0321 g/mole
Tritium decay heat	= 1.954 W/mole

Reference for Constants

Souers, P.C. "Hydrogen Properties for Fusion Energy." University of California Press, Los Angeles, 1886, p 105-106.

Calculation of Decay Heat from Tritium Inventory

Tritium inventory in ITC = 443977.8 Ci
Tritium inventory in ITC = 45.67 g
Tritium inventory in ITC = 7.57 moles

ITC beta decay heat = 14.80 watts

Experimental Measurement
of beta decay heat = 14.56 watts
(Appendix A-5.0)
Difference = 0.24 or 1.6%
No evidence for cold fusion

8.0 Neutron Counting Data

Neutron Counting Time	Counts for Full ITC 443978 Ci	Counts for Empty ITC 0 Ci	One Standard Deviation
1000 sec	47	54	7.3
2000 sec	89	101	10.0

Neutron levels for background (empty ITC) and filled ITC agree to within about one standard deviation. No evidence for cold fusion.